Area Measurement of Skin Friction in Complex Three-Dimensional Flows

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A surface-imaging skin-friction instrument provides measurement of the wall shear-stress vector over a large surface region during a single wind tunnel test using an oil-film interference method. During a test, a camera captures images of the fringe pattern produced by illuminating an oil film with quasi-monochromatic light. By using a visual tracer in the oil, the surface streamlines can also be determined. Analysis of the fringe images using a Hilbert-transform-based technique determines the oil thickness distribution in the region where fringes are visible. A combination of the oil thickness and surface direction is then used to calculate the surface shear-stress distribution by numerically solving the thin-oil film equation:

where τ_x and τ_z are the x- and z-components of the surface shear stress, and μ is the dynamic viscosity of the oil. All quantities in this equation are known from the height measurement except τ_x and τ_z. However, an additional piece of information is needed to solve this equation. If the surface streamline direction γ is obtained from visual tracers or from a streamline image, then $\tau_x = \tau \cos(\gamma)$ and $\tau_z = \tau \sin(\gamma)$, and the equation may be solved for τ.

To test the technique in a demanding situation, it was applied to a three-dimensional (3-D) flow in which a cylinder is mounted normal to a flat plate. An incoming turbulent boundary layer encounters the vertically mounted cylinder and a highly complex 3-D flow results. The first figure shows oil interferograms taken in this flow indicating regions of reverse flow. These images are analyzed, along with surface

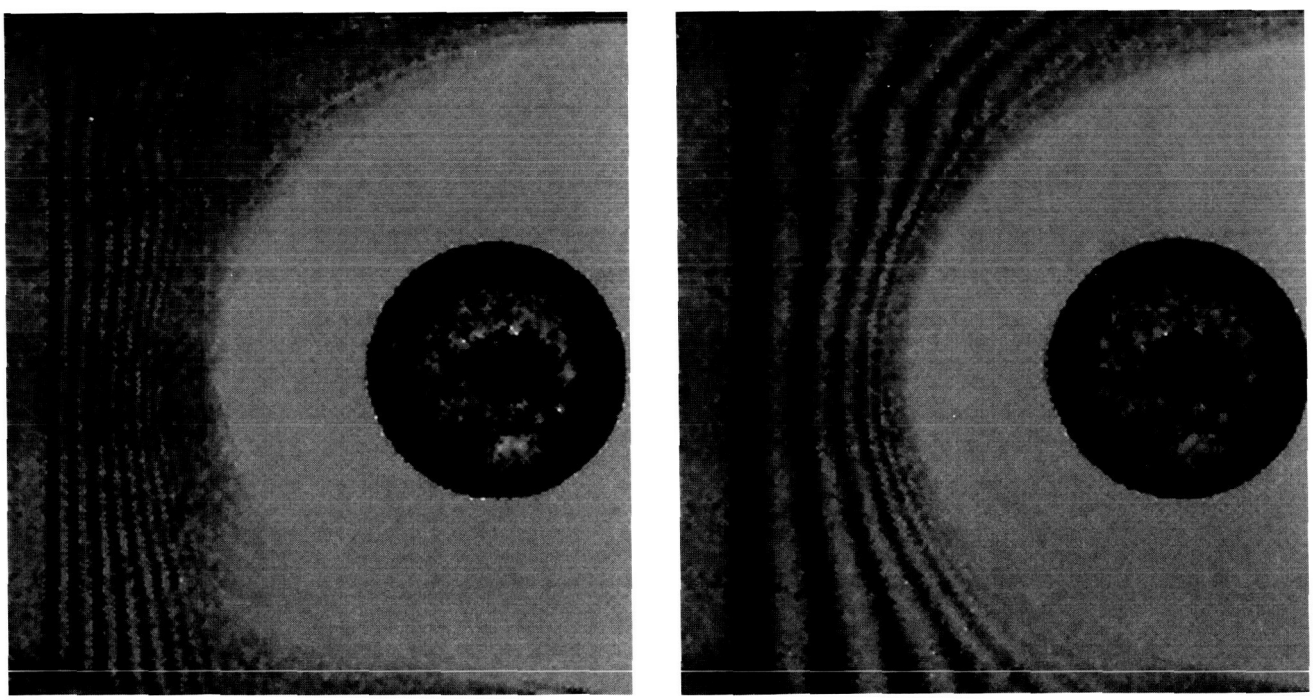

Fig. 1. Oil-film interferogram fringes in front of a cylinder mounted normal to a flat plate.

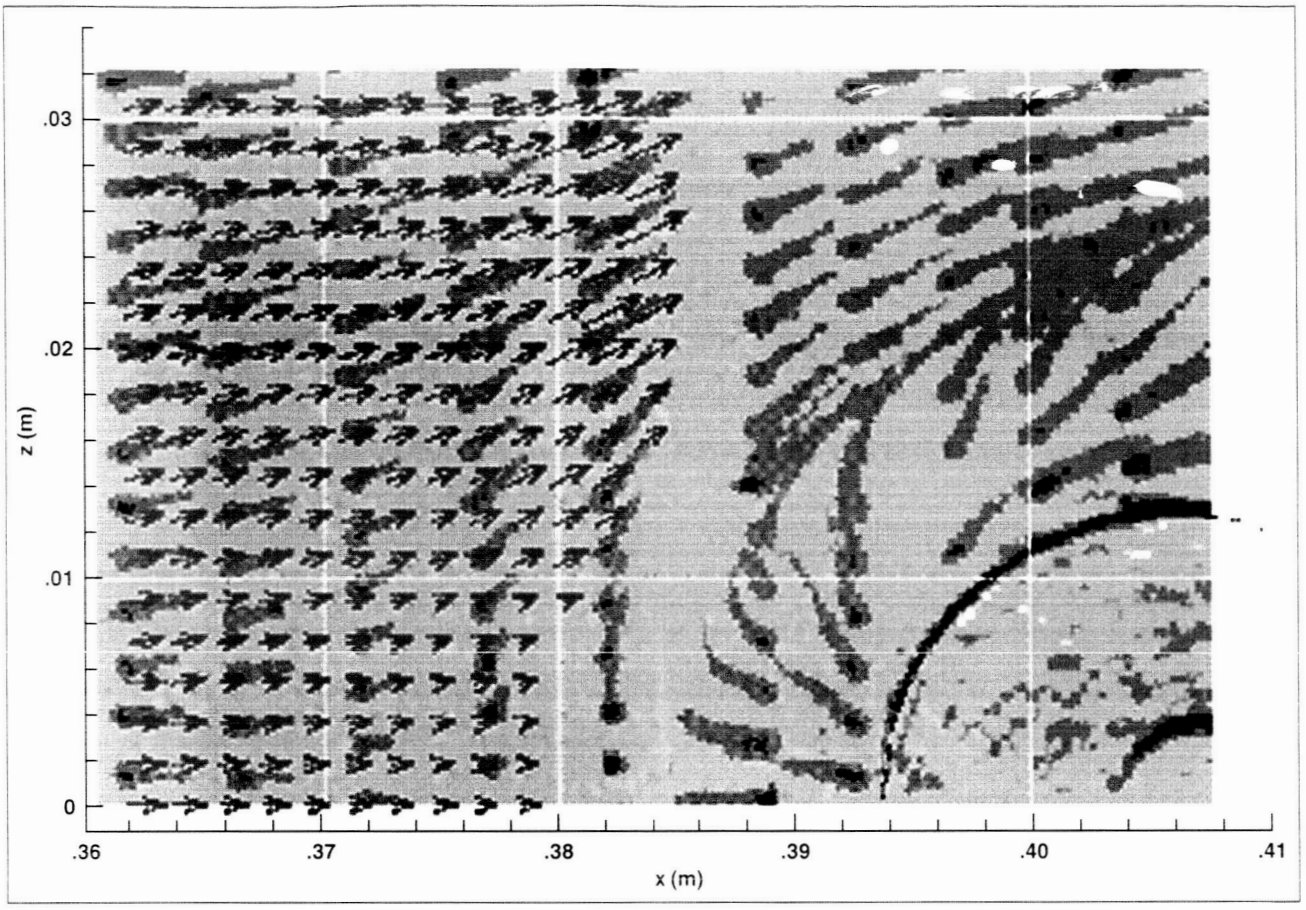

Fig. 2. Shear-stress vectors for a cylinder mounted normal to a flat plate.

streamline images, to determine the surface shear-stress vector field that is shown in the second figure.

The application of the method to the normal cylinder experiment indicates the ability of the instruments to perform in actual flow fields—even in those that are highly complex. An extensive development of the theory has been accomplished to verify the accuracy and theoretical rigor of the analysis techniques used for 3-D flows. A patent assigned to NASA has been applied for and the technology is available for license.

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